Enterprise Cluster Dynamics and Innovation Diffusion: a New Scientific Approach

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Abstract. A model in the field of enterprise management is described in t
work. Its main goal is to represent and analyze the dynamics and interrelati
among innovation diffusion and enterprise clusters formation and modifi
tions. A formal description of the model is given, along that of its main parar
ters. Qualitative results are described. Clustering is definable as the tendency
vertically and/or horizontally integrated firms in related lines of business
concentrate geographically, or, to a more general extent, virtually. Innovatio
a critical factor for the competitiveness of a National System, especially wh
the economy of the latter has come to maturity. However, the diffusion of in
vations among its potential adopters is a complex phenomenon.

Keywords: Innovation diffusion, enterprise network, simulation, model.

1 Introduction

The studies about innovation prove that, beside the creation of innovations
crucial to study their diffusion in the system in which the firms work and
i.e.: the network.

At that level, it is important to clarify what an enterprise network is an
firms start to cooperate inside the network for diffusing an innovation.

A collaborative network is a whole of nodes and ties with a different con
based on of what it has to achieve. These concepts are often displayed i
network diagram, where nodes are the points and ties are the lines. The idea
ing a picture (called a "sociogram") of who is connected to whom for a spec
people is credited to [5], an early social psychologist who envisioned ma
entire population of New York City. Cultural anthropologists independently
the notion of social networks to provide a new way to think about social stru
the concepts of role and position [7], [8], [23], an approach that culminated
ous algebraic treatments of kinship systems [29]. At the same time, in ma
the nascent field of graph theory began to grow rapidly, providing the unde
for the analytical techniques of modern social network analysis.

The nodes represent the different organizations that interact inside the ne
the links represent the type of collaboration between different organizations.

The organizations could be Suppliers, Distributors, Competitors, Custon
sultants, Professional Associations, Science Partners, Incubators, Universi

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for a given market are more likely to collaborate with suppliers and consul
vanced innovators and the development of radical innovations tend to requir
interaction with universities. This point is supported by [15] in a survey
firms in the Lake Constance region (on the border between Austria, Ger
Switzerland). By examining the interactions among firms, customers, sup
universities it emerges that firms that do not integrate their internal reso
competences with complementary external resources and knowledge show
capability of releasing innovations [14].

Philippen and Riccaboni [26], in their work on “radical innovation and
evolution” focus on the importance of local link formation and the process
link formation. Regarding the formation of new linkages Gulati [20] finds
phenomenon is heavily embedded in an actor’s existing network. This mean
ties are often formed with prior partners or with partners of prior partners,
network growth to be a local process. Particularly when considering inte
liances, new link formation is considered “risky business” and actors prefer
that are embedded in a dense clique were norms are more likely to be enforc
opportunistic behavior to be punished [18], [21], [28], [2]. Distant link
implies that new linkages are created with partners whom are not known to
ing partners of an actor. At the enterprise level, [6] shows that distant lin
serve as bridge between dense local clique of enterprises, can provide acce
source of information and favorable strategic negotiation position, which
the firms’ position in the network and industry.

In order to analyze the complex dynamics behind link formation and i
diffusion, as long as their relationships, an agent based model is introduc
work, and is formally analyzed.

2 Network Shape, Collaboration and Innovation Diffusion

The ties representing collaborations among firms can be different in struc
and number.

- type of ties: strong or weak (depending on the type of collaboration:
  development, licensing, research partnerships, joint venture, acquisit
  owner of a given technology);
- structure of ties: long or short (for example industrial districts in which
  geographic clusters or virtual clusters); reciprocal or not (firms that
  competences each other or simply give/take);
- number of ties: dense or not (depending on the number of links a
  firms).

The type and the number of ties affect the network efficiency: for example,
composed of relationships with partners comprising few ties among them wo
control for the principle partner. A network of many non-overlapping ties wou
information benefits: in [30] the authors suggest that the number of col

facilitate the development of trust and cooperation.

The firm's position inside the network is as important as the number an ties. In [6] the authors find that rather than maximizing the number of t should strive to position themselves strategically in gaps between different to become intermediaries. Contrary to this perspective, [3] propose that the tion is one where all the firms are tied only to the focal actor. On the othe suggests that the benefits of increasing trust, developing and improving col and reducing opportunism shapes network structures creating cohesive inter partnerships. These consequent studies highlight that there is no consen which the optimal networking configuration should be. The configuration d the actions that the structure seeks to facilitate.

The firms start to collaborate inside a network for different reasons:

- risk sharing [16]
- obtaining access to new markets and technologies [17];
- speeding products to market [1];
- pooling complementary skills [12];
- safeguarding property rights when complete or contingent contract possible [22];
- acting as a key vehicle for obtaining access to external knowledge [28]

The literature on network formation and networking activity therefore clear strates that whilst firms collaborate in networks for many different reasons common reason to do so is to gain access to new or complementary compete technologies. Those firms which do not cooperate and which do not forma formally exchange knowledge and capabilities limit their knowledge base term and ultimately reduce their ability to access exchange relationships.

When the innovation start to circulate, it can affect the network collabor ciency: firms can decide to cooperate inside the network by developing a exploration behavior, meaning that a firm decides to be related to other org in order to exchange competences and innovations. Otherwise if the firm co internal capability to create innovation as a point of strength, or if the cost exploration is perceived as higher than that of internal research, then it coul assume an internally explorative behavior in which it tries to create new co (and possibly innovations) inside the organization itself.

During the process of innovation diffusion the network can change in th of actors (exit and entry), and in numbers and patterns of link informatio network can expand, churn, strengthen or shrink. Each network change about by specific combination of changes in tie creation, tie deletion, and b in an actor's portfolio size (number of link) and portfolio range (numbers o [2]. It's normal that the modification depends on the original structure of the

Also the propensity to collaborate inside a network affects innovation When a network is a highly collaborative one, the innovation tends to dif quickly, if the ties are dense, non redundant, strong and reciprocal. If the ne described in the following paragraphs, that keeps into account most networ terprise variables.

3 Agent Based Simulation

Why do enterprises team up? There can be many reasons for this strategy, l its widest extent, to the creation of joint-ventures, i.e.: a new economic formed by two or more enterprises with the goal of new projects, or of cl networks of enterprises. The leading cause for these phenomena is the optim the production, by resources and competences sharing. Agent based simula effective paradigm for studying complex systems. It allows the creation societies, in which each agent can interact with others basing on certain agents are basic entities, endowed with the capacity of performing certain ac with certain variables defining their state. In the model presented here, the reactive, meaning that they simply react to the stimuli coming from the en and from other agents, without elaborating their own strategies. When the formally built and implemented, it can be run by changing a parameter at a emergence of a complex behavior occurs.

Agent based Modeling is thus one of most interesting and advanced appr simulating a complex system: in a social context, the single parts and the often very hard to describe in detail. Besides, there are agent-based formalis allow studying the emergence of social behavior through the creation and models, known as artificial societies. Thanks to the ever increasing com power, it has been possible to use such models to create software, based on agents, whose aggregate behavior is complex and difficult to predict, and be used in open and distributed systems.

In [11] we read that: "An autonomous agent is a system situated within of an environment that senses that environment and acts on it, over time, in its own agenda and so as to effect what it senses in the future".

Another very general, yet comprehensive definition is provided by [2 term [agent] is usually applied to describe self-contained programs which c their own actions based on their perceptions of their operating environment"

Agents have traditionally been categorized as one of the following t Reactive; Cognitive/Deliberative; Hybrid.

When designing any agent-based system, it is important to determine ho cated the agents' reasoning will be. Reactive agents simply retrieve pre-set similar to reflexes, without maintaining any internal state. On the other h berative agents behave more like they are thinking, by searching through behaviors, maintaining internal state, and predicting the effect of actions. the line between reactive and deliberative agents can be somewhat blurry with no internal state is certainly reactive, and one that bases its actions o dicted actions of other agents is deliberative.

system, each agent must be able to reason about other agents' actions in add own. A dynamic and unpredictable environment creates a need for an agent flexible strategies. The more flexible the strategies however, the more c becomes to predict what the other agents are going to do. For this reason, tion mechanisms have been developed to help the agents interact when p complex actions requiring teamwork. These mechanisms must ensure that th individual agents do not conflict, while guiding the agents in pursuit of t goals. Many simulation paradigms exist; agent-based simulation is probab that best captures the human factor behind decisions. This is because the m organized with explicit equations, but is made up of many different entities own behavior. The macro results emerge naturally through the interactio micro behaviors and are often more than the algebraic sum of them. This i paradigm is optimal for the purposes of modeling complex systems and of the human factor. The model presented in this paper strictly follows the a paradigm and employs reactive agents, as detailed in the following paragrap

4 The Model

The model is built in Java, thus following the Object Oriented philosoph been engineered and built at the e-business L@B, University of Turin. This for agent based modeling, since the individual agents can be seen as objec from a prototypal class, interacting among them basing on the internal thods). While the reactive nature of the agents may seem a limitation, it's way to keep track of the aggregate behavior of a large number of entities ac same system at the same time. All the numerical parameters can be deci beginning of each simulation (e.g.: number of enterprises, and so on). Eve the model is seen as an agent; thus we have three kinds of agents: Environ terprises and Emissaries (E^3). This is done since each of them, even the env is endowed with some actions to perform.

4.1 Heat Metaphor and the Agents

In order to represent the advantage of an enterprise in owning different co the "heat" metaphor is introduced. In agent based models for Economics, phor based approach [19] is an established way of representing real p through computational and physical metaphors. In this case, a quantum assigned for each competence at each simulation turn. If the competence (i.e.: developed by the enterprise) this value is higher. If the competence (i.e.: borrowed from another enterprise) this value is lower. This is realisti the model we don't have any form of variable cost for competencies, an internal competence is rewarded more. Heat is thus a metaphor not only fo that an enterprise can derive from owning many competences, but also for t ing and synergic part (e.g.: economy of scale).

can be regarded as a set of costs for the enterprise). If the individual heat ge threshold, the enterprise ceases its activity and disappears from the enviro an aggregate level, average environmental heat is a good and synthetic m monitor the state of the system.

The *Environment* is a meta-agent, representing the environment in which er agents act. It's considered an agent itself, since it can perform some actio others and on the heat. If features the following properties: a grid (X,Y), i.e in the form of a matrix, containing cells; a dispersion value, i.e.: a real numb calculate the dissipated heat at each step; the heat threshold under which an ceases; a value defining the infrastructure level and quality; a threshold o new enterprises are introduced; a function polling the average heat (of grid). The environment affects the heat dispersion over the grid and, bas parameter described above, allows new enterprises to join the world.

The *Enterprise* is the most important and central type of agent in the mod havior is based on the reactive paradigm, i.e.: stimulus-reaction. The goal agents is that of surviving in the environment (i.e.: never go under the mi lowed heat threshold). They are endowed with a heat level (energy) that wi sumed when performing actions. They feature a unique ID, a coordinate s track their position on the lattice), and a real number identifying the heat The most important feature of the enterprise agent is a matrix identifying w petences (processes) it can dispose of. In the first row, each position of identifies a specific competence, and is equal to 1, if disposed of, or to 0 if second row is used to identify internal competences or outsourced ones (in the ID of the lender is memorized). A third row is used to store a value to id owned competences developed after a phase of internal exploration, to d them from those possessed from the beginning. Besides, an enterprise ca tled", or "not settled", meaning that it joined the world, but is still looking f position on the territory through its emissary. The enterprise features a wire behavior: internally or externally explorative. This is the default behavio with which an enterprise is born, but it can be changed under certain circu This means that an enterprise can be naturally oriented to internal explorativ (preferring to develop new processes internally), but can act the opposite considers it can be more convenient. Of course, the externally explorative e have a different bias from internally explorative ones, when deciding what s actually take.

Finally, the enterprise keeps track of its collaborators (i.e.: the list of with whom it is exchanging competencies and making synergies) and has ters defining the minimum number of competencies it expects to find, in ord a joint. The main goal for each enterprise is that of acquiring compete through internal (e.g.: research and development) and external exploration (ing new links with other enterprises). The enterprises are rewarded with hea the number of competences they possess (different, parameterized weights f or external ones), that is spread in the surrounding territory, thus slowly ev and is used for internal and external exploration tasks.

territory) it's sent out to find the best place where to settle. 2) if the enterpr tled and chooses to explore externally, an emissary is sent out to find the bes partners. In both cases, the emissary, that has a field of vision limited to the ing 8 cells, probes the territory for heat and moves following the hottest cell finds an enterprise in a cell, it probes its competencies and compares them possessed by its chief enterprise verifying if these are a good complement (to the parameter described in the previous section). In the first case, the en settled in a cell which is near the best enterprise found during the moveme second case, the enterprise asks the best found for collaboration).

While moving, the emissary consumes a quantum of heat, that is direct dant on the quality of infrastructures of the environment.

The movement of the emissaries is based on reactive rules; it follows cells it meets on its path and, if an enterprise is found, it checks for the com ry competences, in order to propose a link with the parent enterprise.

In the following paragraph a formal insight of the model is given throug defining equations, for the agents and the general rules.

5 Underlying Formal Equations

In order to formally describe the model, a set of equations is described in the f

The multi agent system at time T is defined as:

$$MAS_T =< \overline{E}, \overline{e}, \overline{\varepsilon}, \overline{link} > .$$

Where $\overline{E}$ represents the environment and is formed by a grid $n * m$, and a set

$$\begin{cases} \overline{E} =< n * m, \overline{k} > \\ n, m > 0 \end{cases} .$$

Where the set $\overline{k}$ definines the heat for each cell, $\overline{e}$ is the set of enterprises w dinates on the grid, and $\overline{\varepsilon}$ is the set of the emissaries, also scattered on the gr

$$\begin{cases} \overline{k} =< k_{i,j} > \\ \overline{e} =< e_{i',j'} > \\ \overline{\varepsilon} =< \varepsilon_{i'',j''} > \\ 0 < i, i', i'' \leq n \\ 0 < j, j', j'' \leq m \end{cases} .$$

Each enterprise is composed by a vector $\vec{c}$, and an emissary (ε_e). The vector the owned competences, with a length L and competences C_l represented lean variable (where 1 means that the l^{th} competence is owned, while 0 n it's lacking):

$$C_l = \text{Boolean}$$

In $T = t > 0$, $k_{i,j}$ that's the heat of each cell on the grid, depends on the duced by the enterprises (K_e) and the dispersion effect (d). The heat of e prise is function of the competences it possesses and of the behavior it car the last turns (b_e).

$$\begin{cases} k_{i,j} = f(K_e, d) \\ K_e = f(\vec{c}_e, b_e) \\ b \in \bar{b} \\ \bar{b} =< \textit{set of behaviors} > \end{cases}.$$

In particular, a certain behavior can be successful, meaning that at the end of internal or external exploration, a new competence (internal or outsource tively) will be possessed. Otherwise, a it's unsuccessful when, after som research and development (internal exploration) or external market research partner, nothing new is found, and thus the l^{th} competence remains zero.

$$\begin{cases} \begin{cases} \text{if } (b = \text{success}) \text{then } C_l = 1 \\ \text{else } C_l = 0 \end{cases} \\ b \in \bar{b} \end{cases}.$$

At each time-step the set of links (connecting two enterprises together) i basing on the competences of the enterprises.

$$\begin{cases} \overline{\text{link}} =< \textit{link}(e_{i,j}, e_{i',j'}) > \\ \text{link}(e_{i,j}, e_{i',j'}) = f(\overrightarrow{c_{e_{i,j}}}, \overrightarrow{c_{e_{i',j'}}}) \end{cases}.$$

Specifically, when an enterprise does external exploration, it looks for a goo i.e.: an enterprise with a number of competences to share. So, if an enterpr vector like $\boxed{1}\boxed{0}\boxed{0}\boxed{0}\boxed{1}$ meets one with a vector like $\boxed{0}\boxed{1}\boxed{1}\boxed{1}\boxed{0}$ then perfect match and the two enterprises will create a link among them, to reciprocally missing competences. This is the perfect situation, but not the o which two enterprise can create a link; in fact, it's enough that there is at competence to reciprocally share. The strength of the link is directly propo the exchanged competences. This set of equations and rules is enough to e effects on the network of the behaviors of the enterprises, namely the way the firms are managed (externally or internally focused). Though the mod also to explore the effects on innovation (i.e.: a competence that's possesse one enterprise).

In $T = t' > t$ a radical innovation can be metaphorically introduced in t (this is called "shock mode", since this is decided by the user, at an arbitrar means of increasing the length of the vector of competences of a specific ent

Meaning that the competence C_{l+1} will be possessed by only one enterpri
time, while the same competence will be lacking to all the others; though,
terprises' vectors will increase in length, meaning that potentially all of the
able to internally develop that new competence through R&D, from then on.

The vector length metaphorically represents the complexity of the sector
in which the enterprises operate; an highly technological sector has many m
tial competences than a non-technological one. So, another kind of "shock
the system is that of increasing the length of the vector by more than one co
and by leaving all the new components to zero for all the enterprises. In
they'll have to develop themselves the new competences by means of inter
ration. The analysis phase is carried on after several steps after t', in order t
the introduction of the innovation impacted the network and the enterprise
the innovation was first introduced. So we have an analysis phase in T
defined as:

$$\begin{cases} MAS_{t'} \text{vs } MAS_{t''} \\ I \rightarrow d\theta\,\text{link};\ d\theta\,e; d\theta\,k \end{cases}.$$

Namely, the comparison among the system at time $t'$and the same system a
since the innovation has differential effects on the number (and nature) of
on the number of enterprises and the heat of the cells composing the env
always depending on the managerial behavior of the involved enterprises.
ginning of a simulation, the user can change the core parameters, in order t
particular scenario to study and analyze.

6 Conclusion and Qualitative Results

The impact of innovation diffusion on the network depends on the collabo
gree of the system. If the network is collaborative the diffusion of innovati
thens the ties and increases the number of the links among organizations.
are more inclined to exchange competences than to create them inside the
tion: they favor an externally explorative behavior that obviously streng
network. In order to study the complex social dynamics and interrelatio
innovation diffusion and collaborative/non-collaborative networks, an ag
model is introduced in this work and described in details. Even if beyond th
of the present work, some qualitative results coming from the simulator
here, in order to show that this model can be effectively used as a tool for st
dynamics of different base scenarios. As shown in figure 1 and figure 2, w
output graphs obtained from the E^3 simulation model are depicted, a co
network (A1) is defined by the existence of a large number of strong ties (
to the number of enterprises). In our example, there are 10 strong ties amo
terprises. In a network structured in this way, the introduction and consequ
sion of an innovation strengthens the collaborations through:

In this case, the "shock effect" described in the previous paragraph introduc
in the networks that affect the decree of collaboration of the network itself.
duction of an innovation in the network strengthens the links among the e
and the collaboration efficiency increases.

On the other side, in the case of a network with low propensity to collabo
strong links do not exist or are a few when compared to the number of e
The introduction of innovation in a network structured in this way can affe
gree of collaboration of the enterprises, according to industry complexit
situation (B1), it's possible to notice two different scenarios. If industry con
not too high (e.g.: the textile industry), as represented in B2, the number of
and the firms prefer to create innovation inside the organization than receivi
other organizations: in this case the firms favor internal exploration. So,
complexity is low, the propensity to collaboration does not change and the e
are still loosely connected. The number of links could even increase, but m
slowly compared to the case of a collaborative network (B2 vs A2).

If industry complexity is high (B3), the diffusion of innovation increases
ber of ties (but less than in a collaborative network) but the structure of tie
in this case, again, the firms prefer an externally explorative behavior. So, in
the propensity to collaborate gets higher than before after the introduction o
vation, but the links are always weaker when compared to the case of a col
network (B3 vs A2).

The analysis carried on through an agent based model allow to study "in
social system, like an enterprise network, and to study the effects of an inno
collaborative and non-collaborative networks. While the purpose of this w
description of the model itself, the qualitative results show that the innovat
sion in a network can create new ties among the enterprises (can thus be reg
driver for ties creation in a network). Though, only in a collaborative netwo
non-collaborative network acting in a complex industry, the number of the
creases significantly, while in non-collaborative networks acting in an indus
is not too complex, the number of links among the enterprises stays more
same, even after the introduction of the innovation (the enterprises being
cused on internal explorative behavior).

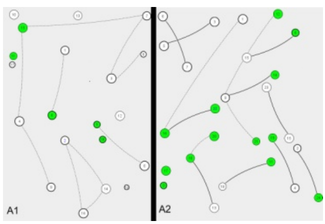

Fig. 1. Collaborative network before (A1) and after (A2) the introduction of an in

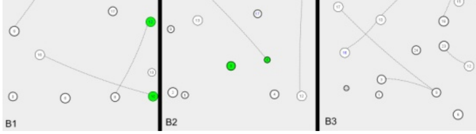

Fig. 2. Non-collaborative network before (B1) the introduction of an innovation. A
case of non complex industry, and after (B3) in case of complex industry.

The presented model is comprehensive and its scope is wide; it could b
study the behavior of enterprises clusters and networks in many different
and situations. In future works quantitative results will be given, and diffe
tions will be analyzed.

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